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The unexpected land use: rain-fed agriculture in drylands

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Although excluded from most maps of current and past land use, dryland rain-fed (non-irrigated) agriculture has been and is pivotal to enhance resilience of human communities, and understand land-atmosphere interactions and regional climate in many parts of the world.

On a warming Earth, reclaiming traditional knowledge related to low-demanding plant varieties and cultivation techniques that reduce land degradation is a priority. Drylands are generally defined as "challenging" for non-irrigated agriculture (Rockström and Karlberg 2009), since artificial watering is considered necessary to secure regular crop yields. The Sahara and its margins are one of the most emblematic drylands. This region is often considered "inactive" from an agricultural point of view (Rockström and Falkenmark 2015). Land-use models and maps of Africa normally characterize the Sahara as a huge empty area stretching from the northern edge of the Sahel up to the Mediterranean coast and the Atlas Mountains. Similarly, current technical reports and studies on food production in drylands (e.g. UNEMG 2011) tend to consider the Sahara devoid of plant cultivation. The amount and extent of rain-fed agriculture in drylands is also important in terms of biogeochemical and biogeophysical processes between land surface and the atmosphere, therefore impacting on climate both in the past and the future.

Rain-fed agriculture in the Sahara

The perceived dominance of pastoralism, together with the idea that hot deserts are unsuitable for raising crops, seems to have eclipsed the role that cultivation has had over time in these regions. It is therefore not surprising that the extent of rain-fed agriculture in the Sahara is poorly researched. Yet, notes published over the last two centuries suggest the occurrence of this practice in different parts of this desert (Fig. 1). In central Mauritania, in the Moudjeria area, where average rainfall is 170 mm a^{-1}, rain-fed crops were observed in the early 1960s (Toupet 1963) and pastoral communities were reportedly growing cereals without irrigation. In the Ahaggar Mountains (also known as the Hoggar Mountains), where the rainfall varies between 0 and 100 mm a^{-1}, millet (without further specification) was grown in the past (see Duveyrier 1864). Nicolaisens and Nicolaisens (1997) reported the existence of a specific word ("*tawgest*"; de Foucauld 1951) to designate non-irrigated plots of land cultivated by the Tuareg people along the valleys of the Ahaggar. In the Aïr massif, where average precipitation is 120 mm a^{-1}, Rodd (1926) wrote that "... in certain areas rain-grown crops could be raised most years. In the past a fair amount of cereals seems to have been produced this way...", obviously hinting at a decrease in this practice. The engagement of nomadic Tuareg with rain-fed farming was reported also in the Tassili n'Ajjer region (now a national park) by the early 1950s (Nicolaisens and Nicolaisens 1997). This practice was further recorded in the Libyan south-west, namely in the Tadrart Acacus (di Lernia et al. 2012), and around the city of Ghat (Bourbon del Monte Santa Maria 1912). These last reports are surprising given the very low (and mostly uneven) rainfall in both those Libyan and Algerian regions, ranging from 0 to 40 mm a^{-1}. In the Tibesti mountain range, close to the Guezendi area, cereal plots were observed in the 1940s (Desio 1942) in areas with less than 50 mm a^{-1} rainfall. This clearly shows a rain-fed agricultural strategy that complements pastoral and foraged resources. Such strategies have been largely ignored in past and current discourse of resource exploitation in the Sahara.

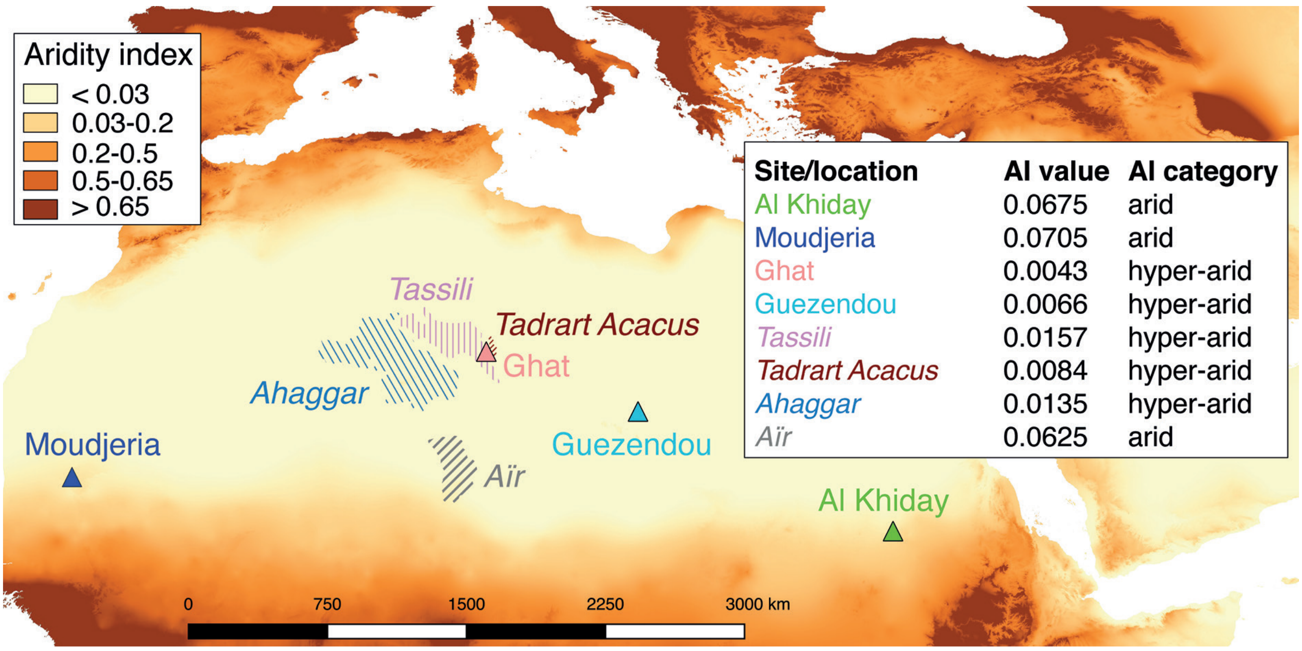

Figure 1: Aridity Index (AI) from the Consultative Group for International Agricultural Research Consortium for Spatial Information (CGIAR-CSI) and the localities mentioned in the text. Triangles indicate specific locations, while shaded areas and italics names refer to regions with evidence of past (and possibly current) plots of rain-fed agriculture. The AI takes into account the values of precipitation, temperature and potential evapotranspiration. The mentioned cases of rain-fed agriculture in the Sahara fall within the "hyper-arid" or "arid" class, well beyond the threshold for the supposed suitability of rain-fed agriculture.

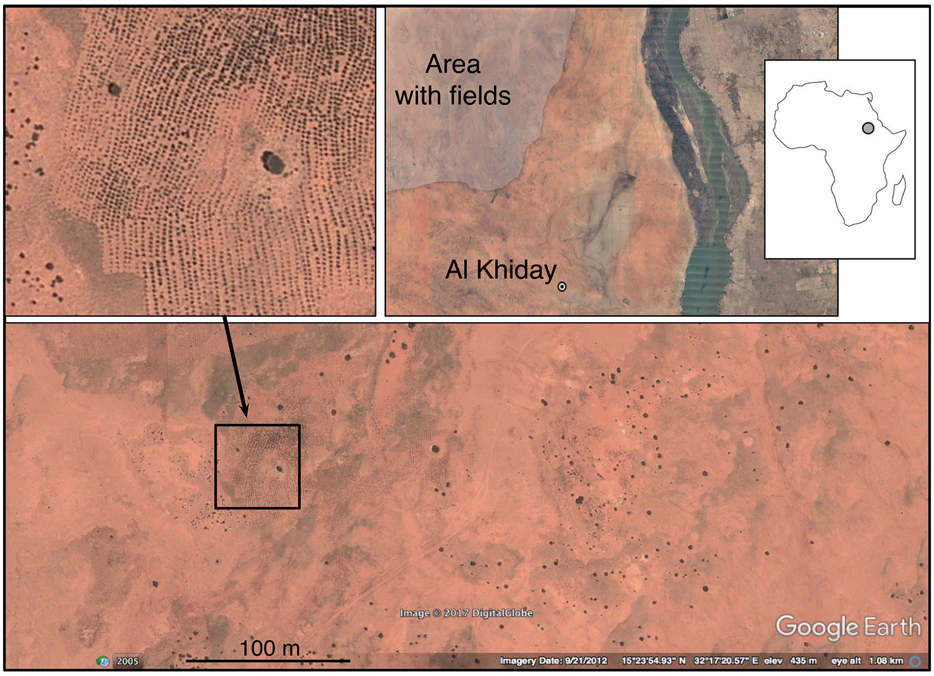

Figure 2: GoogleEarth™ view of one of the fields recorded at Al Khiday. Imagery taken in September 2012. Rows formed by millet plants, ready to be harvested, are shown.

The case of Al Khiday, Sudan

Recent explorations of the desert in the area of Al Khiday in Central Sudan (Fig. 2) are providing new, extensive and systematized data on rain-fed agriculture. The region today is arid (according to both the Köppen–Geigen and the CGIAR-CSI Aridity Index classifications; Zomer et al. 2008) with a yearly average rainfall of ca 100 mm. Several rain-fed fields between 15 and 30 km west of the White Nile left bank were recently surveyed. The observation of free satellite imagery time series (GoogleEarth™) shows that 70 mm of precipitation in July/August is enough to enable the cultivation of extremely large expanses of land (up to ca. 120 ha per field system; Fig. 2). The cultivated areas are divided in plots owned by different families from neighboring villages, whose people are also engaged in wage labor and may own some small stock. The main crop is pearl millet (*Pennisetum glaucum* L. R.Br.), although in wetter years cash crops, such as karkadé (hibiscus), are also cultivated. After the late spring/early summer rains, the fields are prepared by clearing wild grasses (hoeing) while the soil is still wet. Farmers then walk the fields along parallel lines, making holes for seeds roughly every meter. The sown fields are then left unattended until the harvest in September when farmers use iron sickles to cut the plants just above the ground. Grains are then threshed in the fields and the by-products are left for the domestic stock (goats, sheep, donkeys) to graze.

No data are currently available for productivity of rain-fed agriculture in arid or hyper-arid lands, and a first preliminary evaluation of the productivity of the Al Khiday fields gives a value of ca. 100 kg of millet per hectare. This estimate is based on plant density and average single-plant seed production. This figure is clearly much lower than production from the world's dry sub-humid and semi-arid regions, where rain-fed agriculture yields vary between 0,5 and 2 t ha^{-1} (e.g. Wani et al. 2003). In spite of the low yield, local farmers are able to produce double the quantity of millet necessary for the families' annual needs, leaving part of the crop to be sold at local markets after setting aside enough grain for the next planting season. It is astounding that this kind of cultivation not only supplies the families with important dietary carbohydrates, but also supplies some income.

Final remarks

Millets, and specifically pearl millet, are key crops in drylands because of their short growing season and the abundant productivity under aridity and high temperatures. Millets can also be used as fodder, either using the entire plant before grains mature or the by-products from grain processing. They are therefore perfectly suited for mixed agro-pastoral systems. Pearl millet is a critical West African domesticate, and the Sahel zone south of the Sahara is an important area for its domestication (Fuller 2007). However, research on past crops in Africa's drier areas is still limited, and rain-fed practices have never been part of the current discourse on the origin of agriculture, its detection, and extensification/intensification dynamics. Research on ancient rain-fed farming in the Sahara (and other deserts) is urgently needed to address the role of this strategy in enhancing the resilience of human societies in difficult climatic settings. This research, which is in its earliest stages, is proceeding under the framework of PAGES' LandCover6k Land Use group. This working group is producing updated and more realistic assessments of past land use in the light of environmental-human-behavior coupled models. Social science research can greatly enhance the value of this work by connecting present-day adaptive behaviors (traditional ecological knowledge) to the deep historical record. This work has the potential to revolutionize our understanding of the past, as well as current and future resilience strategies and policy, both at domestic and governmental levels. Furthermore, it will inform current research on the Anthropocene by establishing a deep connection between human behavior and its effects on environmental and landscape modifications.

Archaeology plays a pivotal role in exploring rain-fed agriculture through a long-term perspective, which enables the evaluation of adaptive strategies and the resilience of such practices. Thus, it is urgent to plan new archaeological research that can document rain-fed farming in drylands over the past millennia in order to appreciate its frequency, structure and distribution over time and space. This approach should include new archaeobotanical and experimental techniques that unambiguously identify past water-crop management directly from the cultivated crops recovered from archaeological contexts.

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